

Search for eta-mesic helium via deuteron-deuteron reactions with the WASA-at-COSY facility *

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The η -mesic nuclei in which the η meson is bound with nucleus via strong interaction was postulated already in 1986, however till now no experiment confirmed empirically its existence. The discovery of this new kind of an exotic nuclear matter would be very important for better understanding of the η meson structure and its interaction with nucleons. The search for η -mesic helium is carried out with high statistic and high acceptance with the WASA-at-COSY detection setup in the Forschungszentrum Jülich. The search is conducted via the measurement of the excitation function for the chosen decay channels of the ${}^4\text{He-}\eta$ system. Until now two reactions $dd \rightarrow ({}^4\text{He-}\eta)_{bs} \rightarrow {}^3\text{He}p\pi^-$ and $dd \rightarrow ({}^4\text{He-}\eta)_{bs} \rightarrow {}^3\text{He}n\pi^0$ have been measured with the beam momentum ramped around the η production threshold. This report includes the description of experimental method and status of the analysis.

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1. Introduction

Based on the fact that the interaction between the η meson and nucleon is attractive Haider and Liu postulated the existence of the η -mesic nuclei [1], in which the neutral η meson might be bound with nucleons via the strong interaction. The existence of η -mesic nuclei allows to investigate interaction of the η meson and the nucleons inside a nuclear matter. Moreover it would provide information about $N^*(1535)$ resonance [3] and about η meson properties in nuclear matter [2], as well as about contribution of the flavour singlet component of the quark-gluon wave function of η meson [4, 5].

According to the theoretical considerations, the formation of the η -mesic nucleus can only take place if the real part of the η -nucleus scattering length

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is negative (attractive interaction), and the magnitude of the real part is larger than the magnitude of the imaginary part [6]:

$$|Re(a_{\eta-nucleus})| > |Im(a_{\eta-nucleus})|. \quad (1)$$

Calculations for hadronic- and photoproduction of the η meson gave a wide range of possible values of the s-wave ηN scattering length, from $a_{\eta N} = (0.27 + 0.22i)$ fm up to $a_{\eta N} = (1.05 + 0.27i)$ fm. Such a high values has not excluded the formation of η -nucleus bound states for a light nuclei as ${}^3\text{He}$, T [7, 8] and even for deuteron [9]. Those bound states have been searched in several past experiments [10, 11, 12, 13, 14, 15], however none of them gave empirical confirmation of their existence. There are only a promising experimental signals which might be interpreted as indications of the η -mesic nuclei. The ongoing investigations continue at COSY [16, 17, 18, 19, 20, 21], JINR [22], J-PARC [23], MAMI [24] and are planned at GSI [25].

2. Experiment

The measurement of the ${}^4\text{He}-\eta$ bound states is carried out with unique precision by means of the WASA detection system, installed at the COSY synchrotron. Signals of the η -mesic nuclei are searched for via studying the excitation function of specific decay channels of the ${}^4\text{He}-\eta$ system, formed in deuteron-deuteron collision [26, 27]. The measurement is performed for the beam momenta varying continuously around the η production threshold. The beam ramping technique allows to reduce the systematic uncertainties. The existence of the bound system should be manifested as a resonance-like structure in the excitation curve of eg. $dd \rightarrow ({}^4\text{He}-\eta)_{bs} \rightarrow {}^3\text{He}p\pi^-$ reaction below the $dd \rightarrow {}^4\text{He}-\eta$ reaction threshold. The reaction kinematics is schematically presented in Fig. 1.

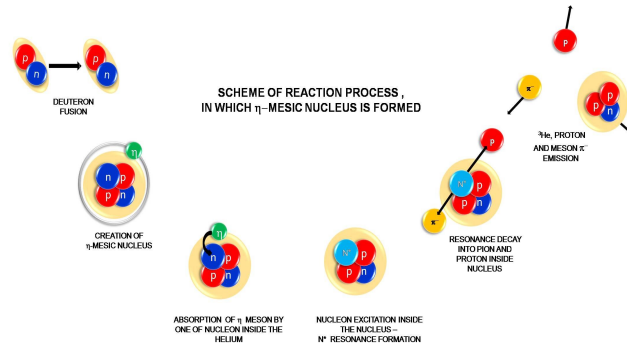


Fig. 1. Reaction process of the $({}^4\text{He}-\eta)_{bs}$ production and decay.

The deuteron - deuteron collision leads to the creation of the ${}^4\text{He-}\eta$ bound system. The η meson can be absorbed by one of the nucleons inside helium and may propagate in the nucleus via consecutive excitation of nucleons to the $N^*(1525)$ state [28] until the resonance decays into the pion-nucleon (n, π^0 or p, π^-) pair outgoing from the nucleus [16]. The relative nucleon-pion angle is equal to 180° in the N^* reference frame and it is smeared by about 30° in the center-of-mass frame due to the Fermi motion of the nucleons inside the helium nucleus.

In June 2008 a search for the ${}^4\text{He-}\eta$ bound state was based on the measurement of the excitation function of the $dd \rightarrow {}^3\text{He}p\pi^-$ reaction near the η production threshold. During the experiment the deuteron beam momentum was varied continuously from 2.185 GeV/c to 2.400 GeV/c which corresponds the excess energy variation from -51.4 MeV to 22 MeV. Excitation function was determined after applying cuts on the p and π^- kinetic energy distribution and the $p - \pi^-$ opening angle in the CM system [29]. The relative normalization of points of the $dd \rightarrow {}^3\text{He}p\pi^-$ excitation function was based on the quasi-elastic proton-proton scattering. In the excitation function there is no structure which could be interpreted as a resonance originating from decay of the η -mesic ${}^4\text{He}$ [30, 31].

During the second experiment, in November 2010, two channels of the η -mesic helium decay were measured: $dd \rightarrow ({}^4\text{He-}\eta)_{bs} \rightarrow {}^3\text{He}p\pi^-$ and $dd \rightarrow ({}^4\text{He-}\eta)_{bs} \rightarrow {}^3\text{He}n\pi^0 \rightarrow {}^3\text{He}n\gamma\gamma$ [17]. The measurement was performed with the beam momentum ramping from 2.127 GeV/c to 2.422 GeV/c, corresponding to the range of the excess energy $Q \in (-70, 30)$ MeV. Until now the $dd \rightarrow ({}^4\text{He-}\eta)_{bound} \rightarrow {}^3\text{He}n\pi^0 \rightarrow {}^3\text{He}n\gamma\gamma$ reaction is analysed. The ${}^3\text{He}$ is identified in the Forward Detector based on the ΔE - E method. The neutral pion π^0 is reconstructed in the Central Detector from the invariant mass of two gamma quanta originating from its decay while the neutron four-momentum is calculated using the missing mass technique.

The excitation function for the $dd \rightarrow {}^3\text{He}n\pi^0 \rightarrow {}^3\text{He}n\gamma\gamma$ reaction is studied for the "signal-rich" region corresponding to the momenta of the ${}^3\text{He}$ in the CM system below 0.3 GeV/c and the "signal-poor" region for the ${}^3\text{He}$ CM momenta above 0.3 GeV/c. The contributions from different background reactions is under investigation.

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